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Design Enhancements to Facilitate a Sustainable and Energy Efficient Dining Facility (DFAC) in a Contingency Environment

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Abstract

DFACs in a contingency environment consume large amounts of energy and resources, and generate large amounts of food and solid waste daily. Almost all Contingency Basecamp (CB) DFACs provide individual paper and plastic ware, which is costly in terms of purchase, transportation, and disposal. This work analyzed the effects of replacing paper and plastic ware with reusable materials, and of adding industrial dishwashers to reduce the logistical burden of using paper and plastic ware. Additional enhancements analyzed were: (1) greywater heat recovery units, (2) solar water heaters, and (3) anaerobic biodigesters. Implementing dishwashing facilities on contingency DFACs was found to be economically viable. Greywater heat recovery was recommended as a standard addition to dishwashing facilities at contingency DFACs. Solar water heating was recommended only at enduring contingency base camps. Anaerobic biodigesters were recommended for base-wide use.

Executive Summary

Except for the command intelligence and operations center, dining facilities (DFACs) are considered one of the most important facilities on contingency basecamps (CBs). In a contingency environment, DFACs serve both as places to eat and as centers where service members can enjoy informal social and work-related functions. In providing these diverse functions, DFACs consume large amounts of energy and resources. In fact, DFACs have one of the highest energy density values (kBtu/ft^2) of any facility type, and generate large amounts of both food and solid waste daily. DFACs commonly use electrical hot water heaters, and expend large amounts of water for both cooking and cleaning. At mealtimes, almost all CB DFACs provide individual paper and plastic ware, even at the large more enduring facilities (MILCON-funded) and locations. The use of disposable table ware is costly, first to purchase and ship the materials, and then to dispose of the spent materials in a continuously generated solid waste stream. The disposal of waste paper and plastic, commonly done by incineration, has recently become more problematic in the Combined Joint Operations Area - Afghanistan (CJOA-A) in that a recently published FRAGO required all burn pits to close NLT 31 July 2013 or have a temporary waiver in place (USFOR-A 2012).

One study and two after-action reviews have recommended that it would be more efficient overall to replace individual paper and plastic ware with reusable materials, and to add industrial dishwashers to clean the reusable materials (Vavrin 2012, 2014; Vavrin, Brown, and Stein 2013). An initial analysis and calculations done by the Bagram Energy Manager in 2012 (included in Appendix A, p 40) supports this recommendation. This change could greatly reduce logistical burden of using paper and plastic ware, but would increase the size of the DFAC to accommodate the dishwashing area and storage, increase the water and electrical requirements, and require additional workers.

This work was undertaken to analyze the effects of replacing paper and plastic ware with reusable individual serving materials and adding a dishwashing station and storage area for the larger CB DFACs. Two DFACs (Dragon and Grady) at Bagram Airfield (BAF), Afghanistan, which are

similar in size and in the number of personnel they serve (a 2,000-person, 700-seat facilities) were selected for analysis.

This study determined that implementing a dishwashing facility, at a one-time capital cost of $2,923,000, will save $724,000/yr, for simple payback of 4 years.

Several additional enhancements to make the DFAC a more sustainable facility were included in the analysis:

1. Greywater heat recovery units to capture and reuse heat from the dishwasher discharge
2. A solar water heater to raise the water temperature before it enters the water heater
3. An anaerobic biodigester that would reduce the amount of solid waste generated and generate methane to use in the DFAC or to fuel a gas-driven generator.

The analysis of these additional improvements determined that:

- A greywater heat recovery system would save 44,000 kWh of energy and $31,000/yr per DFAC, for a payback of 0.31 years. With this quick payback, it is highly recommended that a greywater heat recovery system be included as a standard part of adding a dishwashing facility to a contingency DFAC.
- A solar water heater in combination with a greywater heat recovery system would save an additional 142,000 kWh and $94,000/yr.
- The solar water heater alone would achieve a simple payback in 6 years.
- The combined greywater heat recovery and solar water heaters would achieve a simple payback in 4.4 years.
- Considering these longer payback periods, it is only recommended that a solar water heater be installed at enduring contingency base camps such as Bagram Airfield.

It was determined that an anaerobic biodigester would be more effectively applied as a base-wide (not a DFAC-specific) operation. Since this broader application does not fall under scope of this work, an analysis of the base-wide application of biodigester technology to a CB will being conducted separately.

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Preface

This study was conducted for U.S. Forces – Afghanistan (USFOR-A)." The technical reviewer was James P. Miller, CEERD-CF-E.

The work was managed and executed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL principal investigator was John L. Vavrin. Special gratitude is offered to Keith E. Garrett, Food Service Administrator at the University of Illinois at Urbana-Champaign (UIUC) Ikenberry Dining Hall, for his assistance in preparing the baseline case study for this work. Franklin H. Holcomb is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Acting Technical Director was Kurt Kinnevan, CEERD-CV-T. The Director of CERL is Dr. Ilker R. Adiguzel.

The Commander and Executive Director of ERDC is COL Jeffrey R. Eckstein, and the Director of ERDC is Dr. Jeffery P. Holland.

1 Introduction

1.1 Background

Except for the command intelligence and operations center, dining facilities (DFACs) are considered one of the most important facilities on contingency basecamps (CBs). In a contingency environment, DFACs serve both as places to eat and as centers where service members can enjoy informal social and work-related functions. In providing these diverse functions, DFACs consume large amounts of energy and resources. In fact, DFACs have one of the highest energy density values (kBtu/ft^2) of any facility type, and generate large amounts of both food and solid waste daily. DFACs commonly use electrical hot water heaters, and expend large amounts of water for both cooking and cleaning. At mealtimes, almost all CB DFACs provide individual paper and plastic ware, even at the large, more enduring (MILCON-funded) facilities and locations. The use of disposable table ware is costly, first to purchase and ship the materials, and then to dispose of as part of a continuously generated solid waste stream. Furthermore, the disposal of waste paper and plastic, commonly done via incineration, has recently become even more problematic in the Combined Joint Operations Area - Afghanistan (CJOA-A) in that a recently published FRAGO required all burn pits to close NLT 31 July 2013 or have a temporary waiver in place (USFOR-A 2012).

One study and two after-action reviews have recommended that it would be more efficient overall to replace individual paper and plastic ware with reusable materials, and to add industrial dishwashers to clean the reusable materials (Vavrin 2012, 2014; Vavrin, Brown, and Stein 2013). An initial analysis and calculations done by the Bagram Energy Manager in 2012 (included in Appendix A, p 40) supports this recommendation. This change could greatly reduce logistical burden of using paper and plastic ware, but would increase the size of the DFAC to accommodate the dishwashing area and storage, increase the water and electrical requirements, and require additional workers.

This work was undertaken to analyze the effects of changing to the use of reusable individual serving materials and of adding a dishwashing station and storage area for the larger CB DFACs, specifically, at two DFACs (Dragon and Grady) at Bagram Airfield (BAF), Afghanistan that are similar in size and in the number of personnel they serve.

There is precedence for these DFAC enhancements in a contingency environment. Both the International Security Assistance Force HQs DFAC in Kabul and the German DFAC in Mazar-e-Sharif had permanent tableware and the associated dishwashers to handle the cleaning load. Additionally, the LOGCAP contractor at Bagram Airfield (Fluor) was given the formal direction to provide project planning estimates for adding dishwashers to several DFACs, but due to the uncertainty of longevity of troop presence and the total troop numbers, the projects did not proceed for funding.

1.2 Objectives

The primary objective of this quantitative study was to examine the economic viability of replacing the use of individual paper and plastic ware with reusable table ware at dining facilities in contingency environments, and adding industrial dishwashers to clean the reusable materials.

A secondary objective was to examine the feasibility of adding several additional enhancements to make the DFAC more sustainable:

- greywater heat recovery units to capture and reuse heat from the dishwasher discharge
- solar water heaters to raise the water temperature before it enters the water heater
- anaerobic biodigesters to reduce the amount of solid waste generated and to generate methane for use in the DFAC or as fuel a gas-driven generator.

1.3 Approach

This analysis was conducted using a standard 2,000-person (700-seat) CB DFAC in the Afghanistan region of operation as the base contingency environment. Specifically, this report analyzed two DFACs (Dragon and Grady) at Bagram Airfield (BAF), Afghanistan that are similar in size and in the number of personnel that they serve. Additionally, researchers made a site visit on 11 June 2013 to a University of Illinois at Urbana-Champaign (UIUC) DFAC (Ikenberry Dining Hall), which is roughly equivalent in size and function to the CB DFACs that were the subject of this analysis. Researchers took this opportunity to observe equipment and processes first hand, and to form an operational baseline.

1.4 Scope

Although this work focused on two specific DFACs in the Afghanistan theater, the results of this analysis and recommendations are broadly applicable to most contingency environments.

1.5 Mode of technology transfer

The content of this analysis will be forwarded to the sponsoring agency (U.S. Forces – Afghanistan [USFOR-A]). This report will also be made accessible through the World Wide Web (WWW) at URL: http://libweb.erdc.usace.army.mil

2 Discussion

2.1 Case study

Part of this study involved visiting a DFAC (Ikenberry Dining Hall) at the nearby University of Illinois Urbana-Champaign on 11 June 2013. Ikenberry hall seats 1,200 and serves approximately 4,900 meals/day: 400 for breakfast, 2,000 for lunch, and 2,500 for dinner. The 2,000 PAX DFACs under consideration for this report serve approximately 6,320 meals/day, or 30% more meals per day than are served at the UIUC DFAC. Also, Ikenberry Dining Hall does not use trays; the recommend configuration for military DFACs includes trays.

At the UIUC DFAC, the patrons bring all used dishes to a single collection station; they place the dishes on a three-level, ~20 ft long conveyor system built into the wall that carries the dishes directly to the dishwashing station, eliminating the need for workers to transport the used dishes.

The floor dimensions of the dishwashing area were estimated at 30 by 80 ft (2,400 ft^2). Inside the dishwashing area, the leftover food was first removed. Next the dishes were set to the pre-rinse area where the remaining food was removed (the dishes appeared quite clean after this stage). It was reported that this pre-rinsing used 7 gpm when operating. The facility used a Champion brand conveyer-type dishwasher (rackless), model type unknown (worn off) with an overall length of ~20 ft. Dishes passed through the dishwasher in approximately 80 seconds.

This dishwasher used approximately one 8-lb container of soap and 0.5-gal (half a 1-gal container) of liquid rinse aid daily. This dishwasher was run approximately 90 minutes per meal, or 4.5 hrs/day. The entire dishwashing station was run by eight to 10 people, including those who scrape the plates, those who work the pre-rinse station, and those who load and unload the dishwasher.

The UIUC POC reported that the facility stocked approximately enough dishes for 1.5 times the cafeteria's seating capacity. All the dishes were stored in the dishwashing area in movable carts. Dish storage took an estimated 450 ft^2 of the estimated 2,400 ft^2. Researchers noted that the operating dishwasher radiated a good deal of heat; it was very warm standing next to it. The building's Heating, Ventilating, and Air-Conditioning (HVAC) system will have to be designed to accommodate this heat gain.

2.2 Assumptions

This analysis is based on the following assumptions:

1. All food not served is eventually thrown out. None of it is given to the local national workers to take home or provided to the local populace.
2. All DFAC workers (managers, shift supervisors, cooks, servers, cleaners, other general laborers) eat their meals in the DFAC. (The number of staff per shift is 15% of total DFAC seating population.)
3. Electricity is currently the principal power and energy source. Natural gas or propane is not available. There are JP-8 fuel-fired Domestic Hot Water heaters at Grady and Dragon DFACs on Bagram Airfield.
4. The DFAC operates 365 days/yr.
5. The 2010 analysis of solid waste from a DFAC in Afghanistan is accurate.
6. Each dishwasher runs 60 minutes before and 60 minutes after each meal. (Each meal last 90 minutes; total time running/day/dishwasher = 14 hrs)
7. The cost in a contingency environment is about 3 times the typical U.S. cost. (Note: This cost factor can vary dramatically depending on location.)

Table 2-1 lists the quantitative values associated with these assumptions that are used in the calculations throughout this analysis.

Table 2-1. List of facts and assumptions used in this report.

Item	Value	Notes/Reference
Inflation Factor	2.3% per yr	Average inflation rate over the past 3 years (USDOL 2013)
Burden Factor	3	An assumed factor used to increase the cost of goods and services used in Afghanistan, not construction, see below
Cost/ft^2 of facility	$559	Cost per square foot of a DFAC built at Bagram Airfield between August 2011 and May 2012 (DoD 2010)
fully burdened cost (FBC) of solid waste disposal at Bagram AF	$0.13/lb	Annual cost of $9,343,774 to dispose an estimated 39,420 tons of solid waste in 2010, with a 2.3% annual inflation rate (Keysar et al. 2010)
FBC of power at Bagram AF	$0.70/kWh	US Army Corps of Engineers (USACE) Reachback Operations Center (UROC) calculated value in 2012

Item	Value	Notes/Reference
Average efficiency of electric water heater	88%	WBDG (2011)
Average efficiency of solar water heater	40%	WBDG (2011)
Average wastewater disposal cost at Bagram AF	$0.014/gal	Annual cost of $17,738,163 to dispose an estimated 39,420 tons of solid waste and 640,575,000 gal of wastewater in 2010 with solid waste disposal costing $9,343,774, with a 2.3% annual inflation rate (Keysar et al. 2010; Brent et al. 2010)

2.3 Current configuration

Almost all CB DFACs use disposable individual paper and plastic ware, even the larger, more enduring (MILCON-funded) facilities and locations. Using disposable table ware at large DFAC that serve 2,000 people per meal, four meals a day (breakfast, lunch, dinner, and midnight), consumes a demand for a large amount of table ware that must be transported to the facility and that generates significant quantities of unnecessary paper and plastic waste that must be disposed. Information regarding the use of the DFACs (Table 2-2) and the daily waste generate at Bagram Airfield as reported by LOGCAP was used to determine the cost of disposable dishes used at a 2,000 person DFAC.

Table 2-2. Breakdown of the use of the DFACs at Bagram Airfield by meal.

	Breakfast	Lunch	Dinner	Midnight
Use	60%	115%	95%	25%
Note: Percentages provided by LOGCAP DFAC Analysis, 2010, see Appendix B, p 41				

Assuming that all DFAC workers eat at their DFAC, and that the workforce equals 15% of the DFAC seating capacity, a 2,000 person DFAC serves 6,320 meals per day. Based on pricing information and the use of individual dishes provide by LOGCAP (see Appendix B, p 41), the cost for disposable dishes per day at a 2,000 person DFAC is $2,541 (using 2010 values and assuming 10% waste, Table 2-3). Accounting for inflation and for the added costs of being in a contingency environment (which assumes a yearly inflation rate of 2.3% and a burden factor of 3 for contingency environments), the cost is $8,160/day.

Table 2-3. Daily costs under the current DFAC configuration.

	Purchase dishes	Dispose of used dishes	Totals
Daily costs	$8,160	$116 (894 lb)	$8,276
Yearly costs	$2,978,000	$42,000 (326,000 lb)	$3,020,000

In addition to the cost of supplying the disposable table ware to the DFAC, the used ware must be disposed of. A 2,000 PAX DFAC generates 894 lb of used disposable dishes per day (see see Appendix B, p 41), adding to the logistics burden of waste handling at the location. With an FBC of $0.13/lb to dispose of solid waste at Bagram Airfield,* disposing of the used dishes costs $116/day. However, due to recent FRAGO (USFOR-A 2012) that required all burn pits to close NLT 31 July 2013, or to operate only if they have a temporary waiver, the cost to dispose of solid waste (and the base value of $0.13/lb) is expected to increase.

2.4 Recommended configuration

Switching from disposable paper and plastic ware to reusable dishes and the addition of a dishwashing area to a DFAC can reduce or eliminate the cost of supplying disposable dishes and reduce the amount of solid waste generated. However, adding a dishwashing station will also increase certain costs. The DFAC will use more electricity and water. It will incur a large initial investment to purchase the dishwashing equipment, dishes, and to build an addition to hold the dishwashing station. Finally, the additional personal required to run the equipment will increase labor costs.

2.4.1 Unchanged data

The addition of a dishwashing area will leave some DFAC functions and characteristics, and their associated costs, unchanged:

- number of personal served (meals consumed by additional workers is negligible compared to total)
- amount of food served (food consumed by additional workers in negligible compared to total)
- washing of pots, pans, and serving utensils
- amount of food waste

* Based on an FBC of $9,343,774 to dispose an estimated 39,420 tons of solid waste in 2010 [Keysar et al. 2010] with a 2.3% annual inflation rate.

- personnel cleaning tables
- personnel serving and cooking.

These unchanged quantities (and costs) will not be considered in this analysis, and the associated operating costs for each configuration will not include them.

2.4.2 Dishwasher requirements

To account for the maximum amount of dishes required, it is assumed that each meal is eaten with a complete set of dishes: tray, dinner plate, small plate, bowl, set of flatware, cup, and coffee cup. In addition, the total dish count is augmented by 5% to account for waste (e.g., dropping dishes on the floor, taking a new dish when getting additional servings). Based on the established breakdown of DFAC use (Table 2-2), and counting a set of flatware as one dish for washing purposes, 46,452 dishes are used per day.

Assuming that the dishwasher(s) will be run at full capacity an hour before and after each of four meals, and during the meals (which last 90 minutes), the dishwashers will run 14 hr/day, and must be capable of handling 3318 dishes per hour. Assuming that a commercial dishwasher can wash 20 dishes per rack,* the dishwashing station must be capable of washing 166 racks per hour.

Three commercial dishwashers were compared (see Appendix C, p 42) to determine the average requirements for a commercial dishwasher. This analysis used a generic commercial dishwasher based on the reported specifications of the examined dishwashers.

Table 2-4. Generic commercial dishwasher used in this report.

Racks/hr	Total power (kW)	Water usage (gal/rack)	Inlet Temp. (°F)	Operating Temp. (°F)	Total Cost (w/Conveyor)	Floor Dimensions
200	32	0.50	140	180	$50,000	13 x 7 ft

* Based on 25 dishes per rack for two of the three commercial dishwasher examined or 18 plates/36 glasses per rack (McGuire 2011).

2.4.3 Operation and maintenance (O&M)

Adding a dishwashing station to a CB DFAC increases: the amount of electricity for both the dishwasher power and the additional cooling load on the building HVAC system; and water used; the number of workers employed; and the amount of maintenance required. It also adds the entirely new cost of purchasing dishwashing chemicals and replacement reusable dishes. This analysis assumes that some disposable dishes will still be used for carryout meals, which will incur a purchasing and disposal cost.

2.4.3.1 Water usage

Based on the specifications from the generic commercial dishwasher, only one commercial dishwasher is required. If the dishwasher expends 0.50 gal/rack, and washes 166 racks/hr for 14 hours a day, it will use 1162 gal of water daily.

A manual pre-rinse station, which will most likely be used, will also use water, in addition to that used by the dishwasher. A site visit to the University of Illinois at Urbana-Champaign (UIUC) DFAC revealed that the pre-rinse at that site used 7 gpm and was operated 4.5 hr/day. However, the flow rate for a pre-rinse nozzle is mandated to be less than 1.25 gpm at government facilities (USDOE 2012). Assuming that this mandate is followed, the four pre-rinse heads required for the process would use 6 gpm. If the four pre-rinse stations run continuously during the operation (14 hrs/day), they will use another 4200 gal of water per day. Together, the dishwasher and pre-rinse station will use a total of 5362 gal of clean water per day.

No data were found on the FBC of non-potable water at Bagram Airfield or in the Afghanistan region of operations. The cost of tap water in the United States is $0.0023/gal.* Using the burden factor of 3, the cost of non-potable water is $0.007/gal. The required 5362 gal of non-potable water per day will cost $38/day.

As the amount of detergent added per day is miniscule compared to the overall quantity of water, 16 lb of detergent and 1 gal of rinse aid (see Section 2.4.3.3, "Detergent usage," p 11), it will have a negligible effect on the

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* Based on $2/1,000 gal in 2009 (USEPA 2009) with a 2.3% annual inflation rate.

amount of greywater produced. In other words, the amount of greywater produced equals the amount of clean water used, 5362 gal.

The current FBC to dispose of the greywater (collecting and trucking off-site) is estimated to be $0.014/gal.* At this cost, solid waste disposal was reported as costing $9,343,774 (Keysar et al. 2010). This means that it cost $8,968,050 to dispose of 640,575,000 gal of wastewater in 2010, assuming a 2.3% annual inflation rate, and an initial cost of $0.014/gal. Although this cost is for general wastewater (black- and greywater), this analysis uses this cost for disposing of greywater since the no breakdown of the cost by black and greywater was given. Since it presumably costs less (requires less treatment) to dispose of greywater than to dispose of blackwater, this is a conservative cost estimate. With this disposal cost of $0.014/gal of greywater, the total daily cost to dispose of the greywater is $75/day (Table 2-5).

Table 2-5. Daily water usage and associated costs under the recommended configuration.

Type	Amount	Cost
Clean water	5362 gal	$38
Greywater	5362 gal	$75

2.4.3.2 Power usage

In addition to purifying and treating the water, the water needs to be heated before use. The average water temperature supplied at Bagram ranges from 39.8 to 53 °F (Brown 2012), with an average reported value of 45 °F (Energy Conservation Measures taken at Dragon and Grady DFACs). The generic commercial dishwasher needs water supplied at 140 °F. (The dishwasher then heats the water to the required 180 °F). Assuming that the pre-rinse station uses water at 80 °F (pre-rinse water must be comfortable for the workers), 1162 gal/day of water must be heated from 45 to 140 °F, an increase of 95 °F; and another 4200 gal/day must be heated from 45 to 80 °F, an increase of 35 °F.

* Based on a FBC of $17,738,163 to dispose an estimated 39,420 tons of solid waste and 640,575,000 gal of wastewater in 2010 (Brent et al. 2010).

The total power (kWh/day) needed for water heating can be calculated by:

Power (kWh/day) = Specific heat (kWh/gal/°F) * Flow rate (gal/day) * temperature increase (°F)/efficiency (2-1)

With a specific heat of 0.0024 kWh/gal/°F, and assuming an average water heater efficiency of 88% (WBDG 2011), 301 kWh will be required to heat the water for the dishwasher and 401 kWh to heat the water for the pre-rinse station, for a total 702 kWh/day for water heating.

At a cost of $0.70/kWh at BAF, $211/day is used to heat the water for the dishwasher, $281/day is used to heat the water for the pre-rinse station, for a total of $492/day for water heating.

Power is also required to run the dishwasher (including power for the dishwasher to heat the water from the inlet temperature of 140 °F to the operating temperature). The generic commercial dishwasher uses 32 kW of power. Assuming that it runs continuously for the entire 14 hours, the dishwasher will use 448 kWh of energy per day, at a cost of $314/day (Table 2-6).

Table 2-6. Summary of the daily power required by the automatic dishwasher.

	Heat Water for Dishwasher	Heat Water For Pre-Rinse Station	Run Dishwasher	Totals
Power	21.5 kW	28.6 kW	32 kW	82.1 kW
Energy	301 kWh	401 kWh	448 kWh	1150 kWh
Cost	$211.00	$281.00	$314.00	$806.00
Note: savings based on a water heater efficiency of 88%.				

2.4.3.3 *Detergent usage*

The site visit to the UIUC DFAC (see Section 2.1, "Case study," p 4) revealed that they use 8 lb of soap and 0.5 gal of rinse aid per day. Because the DFACs under consideration are 30% larger than the UIUC DFAC, and because they use (and wash) trays, they will require more chemicals. This analysis assumes that they CB DFACs will use double UIUC amount, or 16 lb of soap and 1 gal of rinse aid per day. Based on the average price of two types of commercial dish soap and rinse aid (see Appendix D, p 43), dish soap will cost $34.88/day and rinse aid will cost $28.32/day. Including the burden factor for contingency environments, CB DFACs will spend $190/day on dishwashing chemicals.

2.4.3.4 Disposable dishes

It is assumed that some disposable dishes will be used daily to accommodate carryout meals. This analysis assumes that 5% of all daily meals will be served with disposable dishes. Information provided by LOGCAP (Appendix B, p 41) indicates that the cost for disposable dishes is $7,622/day for 6320 PAX (using 2010 values and assuming 10% waste). After accounting for a yearly inflation rate of 2.3% and adding the burden factor of 3 for contingency environments, the cost is $408/day. This use of disposable dishes generates 45 lb/day of solid waste, which costs $6 a day to dispose at BAF.

2.4.3.5 Replacement dishes

It is expected that the reusable dishes will be replaced regularly (at a rate of 20% per year) due to breakage, loss, theft, and normal wear. It is assumed that the dishes are replaced at a cost equivalent to purchasing them in the United States multiplied by the burden factor of 3. Assuming that there are enough dishes to serve 150% of the DFAC serving capacity, for a total of 3,000 sets, 300 sets of dishes will be replaced each year. At $18/set (see Appendix E, p 45), adding the contingency burden factor of 3 gives a value of $54 a set. This gives a yearly replacement cost of $32,400 or $90/day. At a weight per set of 4 lb (see Appendix E, p 45), the broken or worn out dishes contribute 2,400 lb/yr of solid waste at a cost of $312 or 7 lb/day at $1.

2.4.3.6 Maintenance

The reported cost for equipment maintenance in FY2008 at the Langley AFB DFAC was $30,000 (Hickman 2009). The Langley DFAC is larger than DFACs in contingency environments. The Langley DFAC was 29,801 ft^2 (Hickman 2009), compared to 24,110 ft^2* for a standard 2,000 person CB DFAC (Contingency Center of Standardization 2012). Since the cited Langley DFAC cost covers maintenance for all the DFAC equipment, not just the dishwashing station, this analysis assumes that value as a "worst case" scenario for a DFAC in a contingency environment, and uses that amount as the actual maintenance cost. Accounting for an annual in-

* 20,290 ft^2, plus an additional 3,820 ft^2 for the dishwashing station.

flation rate of 2.3% and adding the burden factor of 3 for operating in a contingency environment, the actual equipment maintenance cost in a contingency environment is $100,800/yr, or $276/day.

2.4.3.7 Additional workers

Based on the site visit to the UIUC DFAC (see Section 2.1, "Case study," p 4), approximately 10 workers will be required to operate the dishwashing station at any one time. This includes workers to remove the excess food from the dishes, to work the pre-rinse station, and to load/unload the dishwasher. The UIUC DFAC is smaller, serves fewer (4,900 to 6,320) meals per day, and runs for a shorter period of time (4.5 to 14 hours per day) than the CB DFACs under consideration here. Since the UIUC DFAC used 8-10 workers, the maximum value was taken. Table 2-7 lists the expected positions of the additional workers are given below.

Table 2-7. Expected positions of the additional workers.

Task	No. of Workers
Remove excess food from dishes	1
Work pre-rinse-station	4
Load dishwasher	2
Unload dishwasher	2
Transport dishes	1
Total	*10*

As this work is low skilled labor, it most likely will be handled by local nationals. In 2010, employment of local nationals at Bagram costs $35,600/yr for pay and allowances, or $17.12 hour at 2,080 hrs/yr (Brent et al. 2010). In 2009, the FBC of employing Iraqi local nationals was reported $35,700/yr (Commission on Wartime Contracting in Iraq and Afghanistan 2011). As the current focus is on the Afghanistan region of operation, the value of employing local nationals at Bagram will be used (although the results are equally applicable in either case as these two values are almost identical). Using an inflation rate of 2.3% per year, the FBC cost of hiring local nations is $18.33/hr. Assuming that 10 additional workers will be required to run the dishwashing station, working three, 8-hour shifts to cover the four meals, the cost to hire 30 additional workers to run the dishwashing station will be $4,400/day. Some of this additional cost will be offset by reduction in the labor and equipment required to handle garbage.

2.4.3.8 Total O&M costs

The total O&M cost for the recommended configuration is estimated to be $6,514/day or $2,378,000/yr. Table 2-8 lists the complete breakdown of the individual components. In addition to the monetary costs of operating a dishwashing facility, several resources and by-products must be factored in, including the additional water and power used and the additional workers required (Table 2-9).

Table 2-8. Daily operating costs under the recommend configuration.

Item	Daily Cost	Annual Cost
Purify incoming water	$38	$13,870
Dispose greywater	$75	$27,400
Heat water	$492	$179,580
Run dishwasher	$314	$114,610
Detergent use	$190	$69,359
Purchase disposable dishes	$408	$149,000
Dispose of disposable dishes	$6	$2,190
Purchase replacement dishes	$90	$32,850
Dispose of replacement dishes	$1	$365
Maintenance	$276	$100,800
Manpower	$4,400	$1,606,000
Total cost	$6,290	$2,296,000
Note: this does not include the items that are unchanged between the current and recommended configurations.		

Table 2-9. Daily resources used and by-products produced as a result of adding an automatic dishwashing station.

Item	Daily Requirement
Incoming clean water	5362 gal
Greywater	5362 gal
Power to heat water	702 kWh
Power to run dishwasher	448 kWh
Detergent use	16 lb of soap, & 1 gal of rinse aid
Disposable dishes	45 lb
Disposal of disposable dishes	45 lb
Replacement dishes	7 lb
Disposal of replacement dishes	7 lb
Manpower	30 workers

2.4.4 Capital costs

Capital costs include costs to construct and set up additional space at the DFAC, and to furnish all the equipment including dishwashers, dishes, storage racks, and water heaters.

2.4.4.1 Purchasing dishes

Based on the assumption that the DFAC will have enough dishes to accommodate 150% of its serving capacity, a total of 3,000 dish sets will have to be initially purchased. At a cost of $18 a set (see Appendix E, p 45) and a burden factor of 3, the initial purchase cost will be $162,000.

2.4.4.2 Dishwashing equipment

Based on the requirements for the generic commercial dishwasher, the DFAC will require only one dishwasher. However, a backup dishwasher will be included in this design to provide capacity in case the primary dishwasher fails, or to help handle surges in the base's population. At a cost of $50,000 per dishwasher and a burden factor of 3, the cost to purchase two dishwashers will be $300,000.

In addition to the dishwashers, The DFAC will need racks to hold the dishes as they pass through the dishwasher. The following assumptions are made to calculate the number and cost of the racks:

- Enough racks will be required to wash 10% of the dishes (racks are unloaded and reused).
- Dish racks hold plates, bowls, and coffee cups at 20 dishes per rack.
- Each flatware rack can hold 80 pieces of flatware (20 sets).
- A cup rack holds cups only (not coffee cups s).
- A rack can hold 10 trays (each rack counts as two large plates).

Based on these assumptions, 60 dish racks will be needed to wash the large and small plates, bowls, and coffee cups s; 30 dish racks will be needed to wash the trays, 15 cup racks will be needed to wash the cups, and 15 flatware racks will be needed to wash the flatware. Based on a cost of $17 apiece for the dish and cup racks, and $20 apiece for the flatware racks, the total cost for racks will be $2085 (see Appendix F, p 47). With a burden factor of 3, the cost to purchase dishwasher racks for a contingency DFAC will be $6255.

Assuming that other equipment must to be purchased (e.g., carts to move the racks) and that such miscellaneous equipment will cost $20,000, or after adding a burden factor of 3 for contingency environments, $60,000; the total cost to purchase the necessary dishwashing equipment for a contingency DFAC will be $367,000.

2.4.4.3 Storage

Storage space and shelving must be large enough to store all the equipment such as the dishes and wash racks. To calculate the amount of storage required, the following assumptions are made:

- Empty dishwasher racks can be stored stacked three high.
- The storage for the dishes is based on the number of racks needed to hold all the dishes.
- An additional 10% of shelving is included to hold the soap, rinse aid, and other miscellaneous items.

Based on the number of racks required to wash the dishes, the DFAC must have storage space equivalent to 1,200 racks to store all the dishes. The DFAC must also have enough storage space to hold 40 racks to store the actual racks when not in use (i.e., 120 racks stored three high). Allowing 10% extra storage space for both dishes and empty racks, the total required storage space must hold 1,364 racks. One shelving unit holds 15 racks,* so 92 shelving units will be required. At a cost of $222 per shelving units, the cost to purchase the shelving units is $20,400. After adding a burden factor of 3 for contingency environments, the cost to purchase this equipment for a contingency DFAC is $60,600.

2.4.4.4 Hot water heaters

Hot water heaters will be required to heat water for the dishwasher and the pre-rinse station. This analysis considered only tankless electrical heaters for two reasons: electricity is the standard form of power at contingency bases, and tankless heaters take up less space and use less energy as they only heat the water when needed. Two streams of hot water are required, 83 gallons per hour (gph) at a 95 °F temperature rise for the dish-

* Based on the dimensions of the racks and the size of the shelving units. (See Appendix F, p 45 for wash rack dimensions and Appendix G, p 47 for shelving unit information.)

washer and 300 gph at a 35 °F temperature rise for the pre-rinse station. This analysis made the following assumptions:

- Separate tankless water heaters will be used for each stream.
- The backup dishwashing and pre-rinse station will have its own set of water heaters.
- One spare water heater will be included for each stream.
- The water heaters must be able to handle 150% of the required flow rate.
- The same type of water heater should be used for both streams.

This means that two water heaters are required: one capable of handling 125 gph at a 95 °F temperature rise, and one capable of handling 450 gph at a 35 °F temperature rise. Two brands of commercial tankless water heaters were examined:

- *Hubbell*. Hubbell's JTX048 satisfies both criteria. It can provide 197 gph at 100 °F or 491 gph at 40 °F for a cost of $6,400 (Hubbell Water Heaters 2012, 2014).
- *Keltech*. The Keltech CN series 54 kW also satisfies both criteria. It can provide 180 gph at a temperature increase of 123 °F or 480 gph at an increase of 45 °F for a cost of $15,500 (Keltech Inc. 2013, 2014).

Six heaters are required (one for each of the two dishwasher, one for each of the two pre-rinse stations, one backup for the dishwashers, and one backup for the pre-rinse stations). Using the average price of the two heaters ($11,000) and adding a burden factor of 3 for a contingency environment, the cost for the water heaters for a DFAC in a contingency environment is $198,000.

2.4.4.5 Building costs

Space will have to be added to the DFACs to house the dishwashing station. The size requirement is determined by the space needed for:

- the dishwashers
- dish storage
- dish collection activity.

The generic dishwasher occupies 13 x 7 ft of floor space. Assuming that the pre-rinse station increases its lengthen by 10 ft and that 10 ft will be required on all sides for operation, 1160 ft^2 will be required per dishwasher, for a total of 2320 ft^2. The required 92 shelving units with a base dimension of 60 x 21-in. will occupy 80 ft^2. Adding enough space to handle mobile shelving units increases the area needed to store dishes to 1000 ft^2. Finally, assuming the task of collecting the dishes requires another 500 ft^2, the total required dishwashing space will be 3820 ft^2.

A 1000 PAX DFAC was built at Bagram Airfield between August 2011 and May 2012 at a cost of $6,047,000, which included the facility; supporting facilities; contingency costs; supervision, inspection, and overhead; and $203,000 for kitchen equipment. The total size of the DFAC was 11,194 ft^2. The unit cost was $540/$ft^2$ (DoD 2010), which included the cost of the kitchen equipment. If the cost of the kitchen equipment ($203,000) is removed, the unit cost to construct the DFAC falls to $522/$ft^2$. Factoring in inflation at 2.3% annually for 3 years (DD 1391 was revised August 2010) increases this unit cost to $559/$ft^2$. At this price, construction of the additional (estimated 3820 ft^2) space for the CB DFAC dishwashing station will cost $2,135,000.

Unified Facilities Criteria (UFC) 4-722-01N (NAVFAC 2013) allocates 1,032 ft^2 for dishwashing and 600 ft^2 for utensil washing for a total dishwashing area of 1,632 ft^2, less than the estimated 3820 ft^2 required for the contingency DFAC dishwashing station. The three elements that make the DFAC dishwashing station larger than the UFC allocation are:

1. The contingency DFAC's spare dishwasher, which requires 1160 ft^2. The spare dishwasher is included because dishwasher breakdown is more critical in a contingency environment
2. The contingency DFAC's dish collection area, which requires an additional 500 ft^2. A dish collection area is necessary because a contingency DFAC does not have a bus staff; base personnel bus their own tables.
3. The contingency DFAC's additional storage area (1,000 ft^2), which is equivalent to 35% of the dishwashing station. This is higher than the UFC guidelines (10 to 25% of the facility floor space) because contingency DFACs are harder to supply than standard DFACs, and therefore require more storage area.

2.4.4.6 Total capital costs

The total capital cost is $2,923,000 ($2.9 million). Table 2-10 lists the specific breakdown of capital costs.

Table 2-10. Required capital costs for adding a dishwashing facility.

Item	Cost
Building Area (3,820 ft^2)	$2,135,000
Dishwashers (2 ea) + Equipment	$367,000
Dishes, Cups, Utensils	$162,000
Hot Water Heaters (Tankless)	$198,000
Mobile Shelving	$61,000
Total	$2,923,000
Note: Costs include setup and installation.	

Figures 1 and 2 show the current and recommended configurations, and the daily demands of each configuration.

Figure 1. Daily operation of the current CB DFAC.

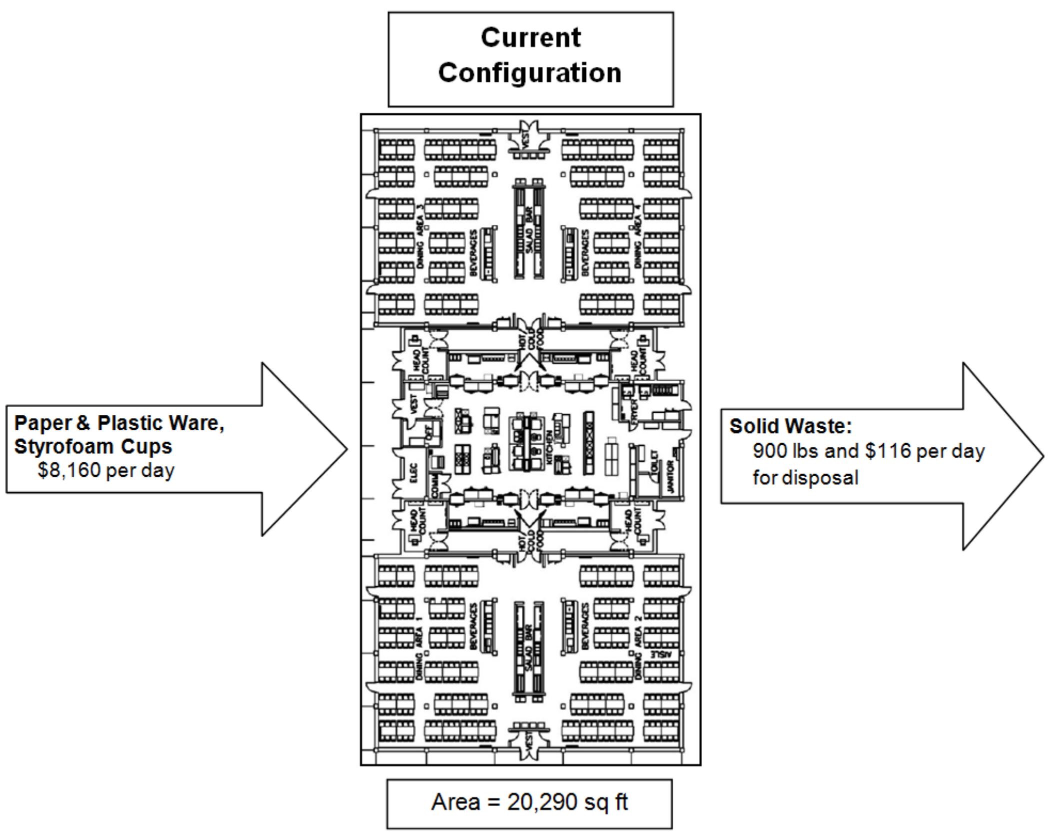
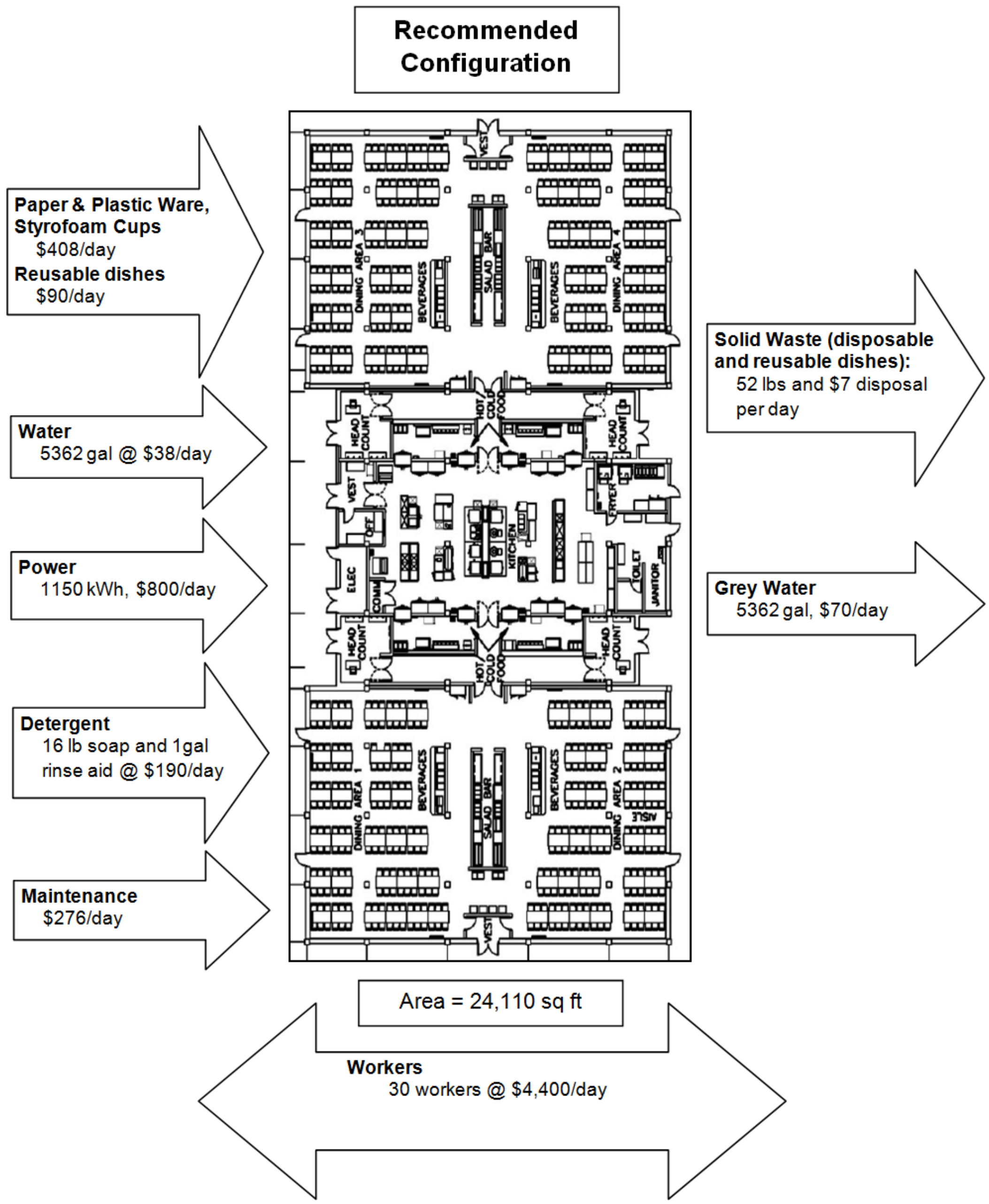


Figure 2. Daily operations of the recommended CB DFAC.



2.5 Savings

Under the current configuration, a 2,000 PAX CB DFAC spends $8,276/day, or $3,020,000/yr to purchase and dispose of paper and plastic ware. Implementing the proposed automatic dishwashing facility will eliminate this cost, and will add an O&M cost of $2,296,000/yr, for a net savings of $724,000/DFAC. At a one-time capital cost of $2,923,000 to construct the dishwashing facility, the simple payback (4 years) is calculated as:

$$\text{Simple payback (yrs)} = \text{Capital cost (\$)/Yearly savings (\$/yr)} \qquad (2\text{-}2)$$

$$4.03 \text{ yrs} = \$2{,}923{,}000/(\$724{,}000/\text{yr})$$

2.6 Sensitivity analysis

The yearly savings and simple payback are influenced the most by two specific factors, the burden factor of 3 to account for the contingency environment and the cost to employ local nationals to run the dishwashing facility. The following sections conduct a sensitivity analysis on these factors to determine how they affect the results. Moreover, since the elimination of the spare dishwasher would significantly reduce the capital cost of the DB DFAC dishwashing facility, the effect of that elimination will also be examined.

2.6.1 Burden factor

The burden factor of 3 used to account for the contingency environment estimates primarily affects the costs of a number of elements in both the current and recommended configurations through:

- the cost of purchasing the disposable paper and plastic ware in a contingency environment (current configuration)
- the DFAC operating costs (recommended configuration) and capital costs of equipment purchase (recommended configuration)
- the cost of disposable dishes and water (current and recommended configurations).

Since this burden factor is used throughout this analysis, yearly savings and simple payback will be calculated at various burden factors values. The results of the sensitivity analysis listed in Table 2-11 indicates that greater savings and shorter paybacks occur at higher burden factors. In other words, as the cost of supplying the contingency basecamp increases, the savings from reducing the necessary supplies by adding a dishwashing station to the DFACs increases.

Table 2-11. Sensitivity analysis of recommended DFAC configuration (effect of Buren Factor on yearly savings and payback).

	Burden Factor (Equipment and Supplies)				
	2	2.5	3 (Baseline)	3.5	4
Yearly savings	-$146,000	$290,000	$724,000	$1,161,000	$1,597,000
Simple payback	No payback	9.6 years	4 years	2.6 years	2 years
Note: shaded cell is the expected value					

2.6.2 Labor rate and number of workers

The cost of labor is critical in determining the payback period. Savings and payback are calculated here for different variations of the hourly wage and the number of workers. This analysis will use values of 25%, 50%, and 150% of the current labor rate of $18.33 an hour, and will vary the current number of workers (10) by ±2 (Table 2-12).

At the expected level of 10 workers/shift, the breakeven labor rate is $26.61/hr. With eight workers/shift, the breakeven rate increases to $33.26/hr at, and with 12 workers/shift, the rate decreases to $22.17/hr.

Table 2-12. The effect of the number of workers and labor rate on the savings and payback (yearly savings [simple payback] at various labor costs).

Labor Rate ($/hr)	Number of Workers/Shift		
	8	10	12
$4.59/hr (25% of baseline)	$2,009,000 (1.45 years)	$1,929,000 (1.51 years)	$1,848,000 (1.58 years)
$9.17/hr (50% of baseline)	$1,688,000 (1.73 years)	$1,528,000 (1.91 years)	$1,367,000 (2.14 years)
$18.33/hr (Baseline)	$1,046,000 (2.79 years)	$724,000 (4.03 years)	$404,000 (7.23 years)
$27.50/hr (150% of baseline)	$404,000 (7.23 years)	-$78,000 (no payback)	-$560,000 (no payback)
Note: shaded cell is the expected value			

2.6.3 Eliminating backup dishwasher

The addition of a backup dishwasher constitutes a significant portion of the capital costs by the purchase price of the second dishwasher and water heaters, but mainly by the construction of the additional required space. This section calculates the savings and payback without the backup dishwasher. Eliminating the backup dishwasher will not change the yearly savings, which remain $724,000/yr. However, the capital costs decrease from $2,923,000 to $2,057,000, a reduction of $866,000. At this lower capital costs, the payback falls from 4 to 2.8 years.

Although removing the backup dishwasher from the facility design significantly decrease the capital cost and shortens the payback period, it increases the chance that a malfunction will render the dishwashing station useless. In a contingency environment, it would be difficult to obtain the necessary parts and personal to repair or replace the dishwasher. If the single dishwasher were to fail, the DFAC would most likely have to return to using disposable paper and plastic ware on an emergency basis for a significant amount of time.

2.7 Adding sustainability enhancements

Several technologies, in addition to the new dishwashing station, may help reduce operating costs and increase sustainability at contingency DFACs:

- a greywater heat recovery (GWHR) system to preheat the water before entering the water heaters
- SWHs
- an anaerobic biodigester waste-to-energy system to reduce the amount of solid waste needing disposal and to generate power.

The following sections evaluate the feasibility of incorporating these technologies, individually and in combination, into CB operations.

2.7.1 Greywater heat recovery

GWHR systems are a non-mechanical systems that transfer waste heat from greywater to the incoming water supply. In a GWHR system, the greywater drain pipe is replaced with a metal pipe (typically copper because of its high heat conductivity) that is wrapped around the metal tubing that carries the incoming water supply (Figure 3). This setup allows the heat from the greywater to preheat the incoming cold supply water. Note that the system keeps both flows completely separate for sanitation reasons. The GWHR system increases the temperature of the incoming water, thereby reducing the amount of energy the water heater expends to heat the water.

Figure 3. Greywater heat recovery unit.

Source: Vavrin (2011)

The primary operating parameter of the GWHR system is the temperature difference between the greywater and the incoming water supply, the greater the difference, the more energy will be transferred from the greywater to the incoming water. To achieve maximum efficiency, the GWHR system needs to be installed vertically (Vavrin 2011). The greywater flowing in the vertical pipe forms a thin layer at the inner surface, maximizing the area available for heat transfer (Decker 2010, Oikos 1995).

Because the pre-rinse station will use water at a much lower temperature than the dishwasher (and its temperature differential is less), its potential for a GWHR system is much less. This analysis will not consider adding a GWHR system to the pre-rinse station.

However, the greywater from the dishwasher offers a significant potential for a GWHR system because there is a large temperature difference between the greywater and the incoming cold water. The average cold water temperature increase for a GWHR has been reported as 25 °F. For commercial dishwashers, the average increase for an incoming cold water supply of 67 °F has been reported as 38 °F (Vavrin 2011).

Because the incoming water supply at Bagram averages 45 °F (Energy Conservation Measures at Dragon and Grady DFACs), the temperature increase will be larger, and has been reported as about 51 °F for incoming water below 67 °F (Vavrin 2011).

This analysis will conservatively assume that the GWHR system increase the water temperature by 38 °F. The savings will be calculated for each of these temperature increases to provide a sensitivity analysis using:

$$\text{Yearly savings (\$)} = \text{cost of energy (\$/kWh)} * \text{specific heat of water (kWh/(gal} * {}^\circ\text{F))} * \text{flow rate (gal/yr)} * \text{temperature increase (}^\circ\text{F)/efficiency of water heater} \quad (2\text{-}3)$$

At a flow rate of 1162 gal/day for the dishwasher for 365 days a year, 424,130 gal will be used per year.

Using the reported cost of power at Bagram of $0.70/kWh (Brent et al. 2010) and a water heater efficiency of 0.88 (WBDG 2011), Table 2-13 lists the yearly savings for a GWHR for each temperature increase: 43,900 kWh and $30,800 at the expected temperature increase of 38 °F. For a sensitivity analysis, the calculations will be repeated at 50% and 150% of the expected electricity price of $0.70/kWh.

Table 2-13. Yearly savings from adding a GWHR.

Temperature increase	Energy price			Yearly energy saving (kWh)
	$0.35/kWh (50% of baseline)	$0.70/kWh (baseline)	$1.05/kWh (150% of baseline)	
25 °F (reported low value)	$10,100	$20,200	$30,300	28,900
38 °F (baseline)	$15,400	$30,800	$46,100	43,900
51 °F (reported high value)	$20,600	$41,300	$61,900	59,000
Note: shaded cells are the expected values.				

Vavrin (2011) reported that, in 2011, four GWHR units were installed in parallel per dishwasher at an installed cost of $1,500 per unit. However, these GWHRs were installed on larger and less water efficient dishwasher that used 6.5 gpm (WaterFilm Energy, Inc. 2010). The dishwashers under consideration here are estimated to operate at a flow rate of 1.4 gpm with a maximum of 1.7 gpm. At this flow rate, only one GWHR unit per dishwasher will be needed. Factoring in an inflation rate of 2.3% per year and a burden factor of 3 for a contingency environment, the cost for each GWHR unit in a contingency environment will be $4,700. The installation of one

GWHR per dishwasher (including the spare dishwasher), for a total of two units, will cost $9,400.

The expected payback time is 0.31 years, and may range from 0.23 to 0.47 years at the current price at Bagram Airfield of $0.70/kWh (Table 2-14). Because the calculated payback periods, even at an electricity cost at half the current value, are all less than a year, it is highly recommend that a GWHR system be installed as part a DFAC automatic dishwashing facility.

Table 2-14. Simple payback of the GWHR.

Temperature Increase	Energy Price $0.35/kWh (50% of Baseline)	Energy Price $0.70/kWh (Baseline)	Energy Price $1.05/kWh (150% of Baseline)
25 °F (reported low value)	0.93 years	0.47 years	0.31 years
38 °F (baseline)	0.61 years	0.31 years	0.20 years
51 °F (reported high value)	0.46 years	0.23 years	0.15 years
Note: shaded cells are the expected values.			

2.7.2 Solar water heater

Solar water heaters using energy from solar radiation to heat water (Figure 4). The incoming cold water is pumped, either by the water pressure in the plumbing lines or by a pump, through the solar water heater where the solar radiation heats it. The primary requirements that determine a solar water heater system's effectiveness are the intensity of the solar radiation and the size of the system. At Bagram Airfield, the average daily solar radiation on a horizontal surface has been reported as 5.14 kWh/m^2/day, with a maximum value 7.69 kWh/m^2/day (maximum value is the average intensity in June, the month with the most solar radiation) (Brown 2012). The size of the system is calculated based on the *Central Solar Hot Water Systems Design Guide* (WBDG 2011).

Figure 4. Solar water heaters installed on a roof (WBDG 2011).

2.7.2.1 Daily load

The daily load at the proposed dishwashing facility is calculated as:

$$L = C_p * Q_{dishwasher} * \Delta T_{dishwasher} + C_p * Q_{prerinse} * \Delta T_{prerinse} = (0.0024\ \text{kWh/gal/°F}) * (1162\ \text{gal/day}) * (95\ \text{°F}) + (0.0024\ \text{kWh/gal/°F}) * (4200\ \text{gal/day}) * (35\ \text{°F}) = 618\ \text{kWh/day}$$

where:

L	=	Daily Load [kWh/day]
C_p	=	specific heat of water [kWh/gal/°F] = 0.0024 kWh/gal/°F
$Q_{dishwasher}$	=	daily flow rate of the dishwasher [gal/day] = 1162 gal/day
$\Delta T_{dishwasher}$	=	temperature increase needed by the dishwasher [°F] = 95 °F
$Q_{prerinse}$	=	daily flow rate of the pre-rinse station [gal/day] = 4200 gal/day
$\Delta T_{prerinse}$	=	temperature increase needed by the pre-rinse station [°F] = 35 °F

2.7.2.2 Estimate solar water heating (SWH) collector size

The estimated SWH collector size for the proposed dishwashing facility is calculated as:

$$A_c = L/\eta_{solar} I_{max} = 618 \text{ kWh/day} /(0.40 \times 7.69 \text{ kWh /m}^2\text{ /day}) = 200 \text{ m}^2 \ (2150 \text{ ft}^2)$$

where:

A_c = collector area [m^2]

L = Daily Load [kWh/day] = 618 kWh/day (calculated previously)

η_{solar} = average efficiency of solar water heater system = 0.40 (WBDG 2011)

I_{max} = maximum daily solar radiation [kWh/m^2/day] (I_{max} in the equation above means the system is designed to meet the load on the sunniest day of the year, which eliminates excess capacity and optimizes economic performance) =7.69 kWh/m^2/day (Brown 2012)

2.7.2.3 Annual energy savings

Annual energy savings for the proposed dishwashing facility are calculated as:

$$E_s = A_c \, I_{ave} \, \eta s_{olar} 365/\eta_{electric} = (200 \text{ m}^2) * (5.14 \text{ kWh/m}^2\text{/day}) * 0.40 * (365 \text{ days/yr}) /0.88 = 170{,}000 \text{ kWh/yr}$$

where:

E_s = annual energy savings [kWh/yr]

I_{ave} = average solar radiation [kWh/m2/day] = 5.14 kWh/m^2/day (Brown 2012).

$\eta_{electric}$ = auxiliary heater efficiency = 0.77 to 0.97, assumed as 0.88 (WBDG 2011)

2.7.2.4 Solar system cost

Solar system cost for the proposed dishwashing facility is calculated as:

$C = c_{solar} A_c = (\$300/ft^2) * (2150\ ft^2) = \$645{,}000$

where:

c_{solar} = per-unit-area cost of installed solar system [$/ft2], typically the installed system price with all the other components is on the order of $75 to $225/ft2 For the size of system considered here, the price is given as $100/ ft^2 (WBDG 2011) = $300/ft^2 at Bagram (average price of $100/ft^2 times the burden factor of 3).

2.7.2.5 Annual cost savings

$$S = E_s C_e - M_f C = (170{,}000 \text{ kWh/yr}) * (\$0.70/\text{kWh}) - (.01/\text{yr}) * (\$645{,}000) = \mathbf{\$113{,}000/yr}$$

where:

S = annual cost savings [$/yr]
C_e cost of energy [$/kWh] = $0.70/kWh
M_f = annual maintenance cost as percent of installation cost [% per year] = 1% per year (WBDG 2011)
C = solar system cost [$] = $645,000 (calculated previously)

2.7.2.6 Simple payback

$$P = C/ S = (\$645{,}000)/(\$113{,}000/\text{yr}) = 5.7 \text{ years}$$

where:

P = simple payback [years]
C = solar system cost [$] = $645,000 (calculated previously)
S = annual cost savings [$/yr] **=** $113,000/yr (calculated previously)

2.7.2.7 SWH savings analysis

The savings and payback of the SWH depend most on the cost of electricity and the cost to install the system (Table 2-15). For the sensitivity analysis, calculations were repeated at 50 and 150% of the reported electricity price of $0.70/kWh. Calculations were repeated using the cost to install the system of $225 to $675/ft^2 (i.e., installation price range reported as $75 to $225/ft^2 [WBDG 2011], multiplied by the burden factor of 3).

Table 2-15. Yearly savings (simple payback) from adding a SWH to a CB DFAC.

Installation Cost ($/ft²)	Cost of Electricity ($/kWh)		
	$0.35/kWh (50% of Baseline)	$0.70/kWh (Baseline)	$1.05/kWh (150% of Baseline)
$225/ft^2 (estimated low cost)	$55,000 (8.8 years)	$115,000 (4.2 years)	$175,000 (2.8 years)
$300/ft^2 (estimated average cost)	$53,000 (12.1 years)	$113,000 (5.7 years)	$173,000 (3.7 years)
$675/ft^2 (estimated high cost)	$46,000 (32 years)	$106,000 (13.9 years)	$165,000 (8.8 years)

Note: shaded cell is the expected value.
Note: the savings decreases with the cost of the system because the maintenance cost is estimated as a fixed percentage of the cost.
Note: savings based on a water heater efficiency of 88%.

2.7.2.8 SWH placement

The amount of space required for the SWH is 2150 ft^2. Because the space in a contingency environment is limited, solar water heaters will have to be mounted on the roof. To avoid extensive retrofitting that would be required to mount solar water heaters on the existing DFAC roofs, only the newly constructed dishwashing station section will be considered for SWH installation. The 3820 ft^2 addition will provide enough room to mount the SWH system on the roof while leaving room for maintenance. This added load to the roof structure will have to be factored into the dishwashing station addition design.

2.7.3 Solar water heater and greywater heat recovery

If a greywater heat recovery system is used in conjunction with an SWH, it will change the temperature increase required by the dishwasher and reduce the daily load (Table 2-16). The rest of the calculations are the same and will not be repeated here.

Adding a GWHR system in conjunction with as SWH yields greater savings and shorter simple payback time than an addition of an SWH alone. Since the payback for the SWH alone is 5.7 years (Table 2-17), it is recommended that a SWH be included as part of the DFAC dishwashing station for any DFAC that has a projected life of over 5.7 years. Since the payback period for a GWHR system is so short it is highly recommended that a GWHR be included with all SWH installations because SWH and GWHR technologies used in combination yield higher savings than does SWH alone.

Table 2-16. Energy and cost savings for a SWH with and without GWHR (energy and cost savings from adding a GWHR and SWH).

GWHR Temp. Increase	Area of Collectors Needed (ft^2)	Energy Saved /yr from SWR (kWh/yr)	Energy Saved /yr from GWR (kWh/yr)	Savings/yr from SWH	Total Savings/yr from SWR and GHR
None	2,150	170,000	None	$113,000	$113,000
25 °F (reported low value)	1,916	152,000	28,900	$101,000	$121,000
38 °F (baseline)	1,787	142,000	43,900	$94,000	$125,000
51 °F (reported high value)	1,668	132,000	59,000	$87,000	$129,000

Notes:
Shaded cells represent expected values.
Savings based on 88% efficiency for standard heating (WBDG 2011).
Savings based on $0.70/kWh for electricity.
The simple payback for just the SWH is given by the capital cost of the SWH divided by the yearly savings.

Table 2-17. Payback of adding a SWH with or without a GWHR.

GWHR Temp. Increase	Cost of SWR	Combined Total Cost of SWR and GWHR	Simple Payback of SWR	Combined Simple Payback of SWR and GWHR
None	$645,000	$645,000	5.7 years	5.7 years
25 °F (reported low value)	$575,000	$584,400	5.7 years	4.8 years
38 °F (baseline)	$537,000	$546,400	5.7 years	4.4 years
51 °F (reported high value)	$499,000	$508,400	5.7 years	4.0 years

Notes:
Shaded cells represent expected values.
Note: Savings based on $0.70/kWh for electricity.

2.7.4 Anaerobic biodigester

An anaerobic biodigester was considered as a sustainability enhancement for a CB DFAC. A biodigester would produce methane gas from food waste, which would reduce the amount of solid waste to be disposed and could be used to produce power. A biodigester is a standalone system that need not be connected to a specific DFAC. Because Bagram Airfield has multiple DFACs, it would be more efficient for one large biodigester to serve the entire base than for smaller digesters to serve each individual DFAC. ERDC/CERL is conducting a separate analysis of adding a base-wide biodigester to a CB, and plans to publish a technical report containing the results of that analysis.

3 Conclusions and Recommendations

3.1 Conclusions

This study concludes that the implementation of dishwashing facilities on contingency DFACs is economically viable, with an expected yearly savings of $724,000 per dining facility and a short payback period of 4 years.

Installation of a dishwashing station in conjunction with a GWHR system is highly effective and economically viable. The GWHR system offers significant energy savings with a payback time shorter than that of the dishwashing facility itself.

For the enduring contingency locations, those with a mission that is projected to last more than 5.7 years after the completion of the dishwashing station, a solar water heater is an effective solution to reduce the energy demand of the dishwashing station. Because SWH has a longer payback than the dishwashing station, it is only cost effective to install it at such enduring locations to ensure that the savings will offset the initial capital expense.

In addition to the monetary and energy savings from implementing a dishwashing facility, there are other non-monetary benefits. Employing the local nationals would improve their standard of living and help to build mutual trust, both of which are key areas of the U.S. counter-insurgency efforts. Additional benefits include a reduction in pollution from burning of waste, a reduction in fuel consumed to truck/handle solid waste, and an overall decrease in the solid waste (landfill) footprint. Implementing a dishwashing station will also employ 30 local nationals per day; helping to improve their standard of living as well as building trust between them and the U.S. and Coalition forces.

Finally, implementing a dishwashing station, especially one that includes GWHR and SWH, will demonstrate the command’s commitment to taking concrete steps to reduce the energy demand, just as they are asking the base personal to do.

3.2 Recommendations

The main requirements for adding a dishwashing facility are an adequate water supply and power generation capabilities. It is recommended that a dishwashing facility be added to DFACs at contingency basecamps that have these resources in the quantities mentioned in this analysis. It is recommended that dishwashing stations, including GWHR systems, be added to DFACs at contingency bases that have sufficient power and water capabilities and that are projected to last more than 4 years after the completion of the facility.

The proposed automatic dishwashing facility includes a backup dishwasher. Although eliminating the backup dishwasher from the facility design results in an $$866,000 reduction in the capital costs and a corresponding reduction in the payback from 4 to 2.8 years, it is still recommended that the backup dishwasher be included. If the backup dishwasher were not included, it would leave the DFAC with a single point of failure where a malfunction could render the dishwashing station useless. In a contingency environment, it would be difficult to obtain the necessary parts and personal to either repair or replace the dishwasher. If the single dishwasher were to fail in this case, it would require the DFAC to switch back to disposable paper and plastic ware for a significant amount of time. However, if the additional cost of including the backup dishwasher would be insurmountable for a particular DFAC, it is recommended in that case to add the dishwashing facility without the backup dishwasher.

In general, if a base is projected to be operational more than 6 years after completion of the project, it is recommended that a solar water heat also be included. Conversely, it is recommended that any location *not* projected to run for 6 years *not* include a solar water heater since the savings will not offset the initial capital costs. However, since solar insolation is location dependant, the final payback value must be calculated separately for each specific site.

Additional significant savings will accrue from using energy efficient appliances in the proposed dishwashing facility. For example, an increase in the efficiency of the water heaters from 80 to 90% would save 32,300 kWh, or $22,600/yr. As long as the expected savings and the planned duration of the basecamp justify increasing the energy efficiency of the various appliances, it is recommended that such energy efficiency appliances should be used. It is recommended that these energy efficient upgrades should consist of using electric water heaters instead of fuel-fired, tankless hot water heaters instead of standard water heaters, low water use dishwashers, a low-flow pre-rinse station, and dishwashers with a heat recovery system for the vented hot air.

Sensitivity analysis showed that yearly savings will decrease or disappear completely if the burden factor drops is less than 2.5, but that it will greatly increase as the burden factor increases. It is recommended that estimates of the burden factor be obtained at the specific CB before installing the dishwashing station to determine if it will be economically viable.

Savings were also found to depend significantly on the labor rate of the local nationals and the number of additional workers required. The proposed dishwashing station was determined to be cost effective in the CJOA-A. However, if other contingency environments are under consideration, the savings at the local labor rate need to be determined or estimated before a complete understanding of the expected savings can be made.

Finally, it is worthwhile to note that the concept of implementing dishwashing facilities on contingency DFACs is not new, even to the Afghanistan Theater; the German owned and run DFAC in Mazar-I-Sharif used permanent tableware and a dishwasher.

Acronyms and Abbreviations

Term	Definition
AF	Air Force
BAF	Bagram Airfield
CB	Contingency Basecamp
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CJOA-A	Combined Joint Operations Area - Afghanistan
DFAC	Dining facility
DoD	U.S. Department of Defense
ERDC	Engineer Research and Development Center
FBC	Fully Burdened Cost
FRAGO	Fragmentary Order
GWHR	Greywater Heat Recovery
LOGCAP	Logistics Civil Augmentation Program
MILCON	Military Construction
NLT	not later than
O&M	Operation and Maintenance
PAX	Personnel
POC	Point-of-Contact
SF	Standard Form
SWH	Solar Water Heating
TR	Technical Report
UFC	Unified Facilities Criteria
UIUC	University of Illinois Urbana-Champaign
URL	Universal Resource Locator
UROC	USACE Reachback Operations Center
USACE	US Army Corps of Engineers
USDOL	U.S. Department of Labor
USEPA	U.S. Environmental Protection Agency
USFOR-A	U.S. Forces – Afghanistan
WBDG	Whole Building Design Guide
WWW	World Wide Web

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Appendix A: Bagram Airfield – Initial Dishwasher Analysis for Grady and Dragon Dining Facilities (DFACs) in 2012

A.1 Facts

Note that the calculations documented in this Appendix were conducted in 2012 by John Vavrin, Bagram Energy Manager.

Grady DFAC

Design Headcount/Meal	
Steady State	2,200
Surge	4,400

Dragon DFAC

Design Headcount/Meal	
Steady State	1,900
Surge	3,800

Amount of time for meals: 90 minutes
Design: Reference (http://www.c-tdesign.com/)

1. To help determine what size dishwashing machine you will need, you must first determine how many racks of dishes per hour you will generate.
    a. Here is an equation that may help: # of pieces per person times # of persons per hour divided by 20 pieces per rack = racks per hour required.
2. High-Temp vs. Low-Temp Ware washing
    a. When thinking about changing to low-temp ware washing from high-temp, remember that you will still need 140° water. Heating water in your hot water heater is less efficient than using a booster heater. Also remember that the chemical usage is directly proportional to the water the dishwasher uses, and most low-temp units use a great deal of water. High-temp is still the most efficient and productive means of ware washing.
    b. Nationwide, health inspectors require that dish machine rinse temperatures be verified to reach between 170 - 212 °F, the range sure to kill bacteria. You must use a mercury-filled thermometer to hold the highest temperature reached.

3. Facility Addition and other Capital Costs (for each DFAC)
   a. Cost/ft^2 of facility: \$200/ft^2
   b. Area needed for dishwashing and storage: 3,000 ft^2
   c. Total Cost for facility addition: \$600,000
   d. Hot Water Heaters (4 ea 100 gal): \$5,000
   e. Dishwashing Equipment: \$100,000
   f. Additional Costs (Plates, Utensils, Cups, Bowls, etc.) = \$30,000
   g. Storage and Racks: \$30,000
   h. TOTAL INVESTMENT COSTS = \$765,000 + 13% USACE Fee ~ \$865,000
4. Additional Annual Costs (O&M):
   a. Water: \$0
   b. Energy (fuel) to Heat Water: \$270,000
   c. Cleaning Products: \$10,000
   d. Trained Workers: \$20,000
   e. Replacement of Dishes, Utensils, etc. = \$2,000
   f. TOTAL ANNUAL O & M COSTS = \$302,000
5. Annual Savings
   a. Trash Hauling (to landfill or off-site): \$10,000 (estimated)
   b. Trash Handling (personnel to process trash): \$4,000 (estimated)
   c. Avoidance Cost of Paper/Plastic Products: \$5,500,000
   d. TOTAL ANNUAL SAVINGS = \$5,501,400

A.2 Payback (years)

Payback = \$1,166,450/\$5,501,400 = 0.21 yrs

Appendix B: Cost of Paper/Plastic Ware at a 2,000 PAX CB DFAC

Table B-1. Costs and weight of paper products per day at a 2,000 PAX DFAC.

Costs and weight of paper products per day at 2,000 PAX DFAC												
average number of meals served / day				6,320								
paper trays									paper trays			
number of trays/bx	weight/ bx	dimensions	cu ft/bx	cost	typical percentage used/ day	trays used/ day	number of boxes used/ day	typical cost/ day	pounds of trays/day	pounds of packing/box	calculated carton weight	estimated total weight
500	30	26x16x18	4.3	$107	80	5056	10.11	$1,082	303.4	2	20.2	324
three compartment round plates									round plates			
number of plates/bx	weight/ bx	dimensions	cu ft/bx	cost	typical percentage used/ day	plates used/ day	number of boxes used/ day	typical cost/ day	pounds of plates/day	pounds of packing/box	calculated carton weight	estimated total weight
500	22	17x9x20	1.8	$73	10	632	1.26	$92	27.8	2	2.5	30.3
styrofoam containers									styrofoam containers			
number of trays/bx	weight/ bx	dimensions	cu ft/bx	cost	typical percentage used/ day	trays used/ day	number of boxes used/ day	typical cost/ day	pounds of trays/day	pounds of packing/box	calculated carton weight	estimated total weight
200	8	19x19x19	4.0	$30	10	632	3.16	$95	25.3	2	6.3	31.6
plastic ware									plastic ware			
number of packets/ bx	weight/ bx	dimensions	cu ft/bx	cost	typical percentage used/ day	packets used/ day	number of boxes used/ day	typical cost/ day	pounds of trays/day	pounds of packing/box	calculated carton weight	estimated total weight
400	18	13x13x15	5.9	$48	105	6636	16.59	$796	298.6	2	33.2	332
styrofoam cups									styrofoam cups			
number of cups/bx	weight/ bx	dimensions	cu ft/bx	cost	typical percentage used/ day	cups used/ day	number of boxes used/ day	typical cost/ day	pounds of trays/day	pounds of packing/box	calculated carton weight	estimated total weight
500	12	20x17x30	5.9	$22	30	1896	3.79	$83	45.5	2	7.6	53.1
small bowls									small bowls			
number of bowls/bx	weight/ bx	dimensions	cu ft/bx	cost	typical percentage used/ day	bowls used/ day	number of boxes used/ day	typical cost/ day	pounds of trays/day	pounds of packing/box	calculated carton weight	estimated total weight
1200	32.5	20x17x30	5.9	$119	15	948	0.79	$94	25.7	2	1.6	27.3
small plates									small plates			
number of plates/bx	weight/ bx	dimensions	cu ft/bx	cost	typical percentage used/ day	bowls used/ day	number of boxes used/ day	typical cost/ day	pounds of trays/day	pounds of packing/box	calculated carton weight	estimated total weight
1000	22	13x12x13	1.2	$106	10	632	0.63	$67	13.9	2	1.3	15.2
Assume: $2/ gal for fuel, fully incumbered cost approaces $30/ gal							subtotal	$2,310			daily subtotal lbs.	813
This equates to a 15x cost increase.						add % wastage	10	$231		add % wastage	10	81
							Total	$2,541			Daily Total lbs.	894
				Fully burden cost factor	3		Daily Cost in 2010	$7,622				
				number of days	365		Yearly Cost in 2010	$2,782,157				
				Yearly Inflation rate	0.023		Daily Cost in 2013	$8,160				
							Yearly Cost in 2013	$2,978,574				

Appendix C: Features of Three Commercial Dishwashers

Table C-1. Features of Champion 54 DR commercial dishwasher.

Racks/hr	Booster heater power	Rinse tank power	Water tank power	Water usage (gal/rack)	Water inlet temp. (°F)	Cost
208[1]	12 kW[1]	3 kW[1]	15[1]	0.43[1]	140[1]	$24,000[1]
Water operating temp (°F)	Conveyor included	Soap/rack	Cost of conveyor	Floor dim.	Conveyor power	
180[1]	No[1]		$24,000[2]	12 x 7 ft[3]	1 kW[3]	
1. http://www.foodservicewarehouse.com/champion/54-dr/p545493.aspx						
2. Estimated that the conveyor costs as much as the dishwasher						
3. http://www.championindustries.com/specs/12.pdf						

Table C-2. Features of Hobart CL44e commercial dishwasher.

Racks/hr	Booster heater power	Pump power	Electrical heating	Water usage (gal/rack)	Inlet temp. (°F)	Cost
202[1]	15 kW[1]	1.5 kW	15 kW[1]	0.62[1]	140[1]	$19,000[1]
Water operating temp (°F)	Conveyor included	Soap/rack	Cost of conveyor	Floor dim.	Conveyor power	
180[1]	No		$19,000[2]	13 x 7 ft[3]	.5 KW	
1. http://www.missionrs.com/CL44E-14.html						
2. Estimated that the conveyor costs as much as the dishwasher						
3. https://my.hobartcorp.com/resourcecenter/ProductDocumentation/F-40268.pdf						

Table C-3. Features of Insinger Admiral 44-4 commercial dishwasher.

Racks/hr	Booster heater power	Wash power	Electrical heating	Water usage (gal/rack)	Inlet temp. (°F)	Cost
233[1]	15 kW[1]	2[1]	15 kW[1]	0.63[1]	140[1]	$23,000[2]
Water operating temp (°F)	Conveyor included	Soap/rack	Cost of conveyor	Floor dim.	Conveyor power	
180[1]	No		$23,000[3]	N/A	1[1]	
1. http://www.insingermachine.com/pdf/specs/Admiral44_2012.pdf						
2. http://www.grainger.com/Grainger/INSINGER-Commercial-Conveyor-Dishwasher-14U212?Pid=search						
3. Estimated that the conveyor costs as much as the dishwasher						

Appendix D: Dishwashing Chemicals

Table D-1. Description of two types of dishwashing chemicals.

	Name	Size	Amount/case	Cost/case	Source	Note
Detergent	Power Green	8 lb	4/case	$86.53	1	biodegradable
	Acclaim	8 lb	4/case	$52.99	2	
Rinse aid	Dry it HD	1 gal	4/case	$109.60	3	
	Rinse Magic Liquid	1 gal	4/case	$116.99	4	

1. WEBstaurantStore.com. 2013. *Noble Chemical Power Green Heavy Duty Solid Machine Dish Detergent*, http://www.webstaurantstore.com/noble-chemical-power-green-heavy-duty-solid-machine-dish-detergent-8-lb-container-4-cs-ecolab-apex-power-17063-alternate/147POWERGREN.html
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4. Food Service Warehouse. 2014.*Enzyme Rinse Magic Concentrated Liquid Rinse,* http://www.foodservicewarehouse.com/enzyme-solutions/3000160/p1458901.aspx

Appendix E: Reusable Dishes for Contingency DFAC with Dishwashing Station

Table E-1. Reusable dishes.

	Trays	Large plates	Small plates	Bowls	Glasses	Coffee Cups S	Fork	Knife	Spoon	Soup Spoon
Cost/piece	$2.45	$5.39	$1.79	$1.79	$1.20	$2.79	$0.56	$1.03	$0.43	$0.56
Weight/piece	0.8 lb	1 lb	0.5 lb[1]	0.5 lb[1]	0.2 lb	0.5 lb[1]	0.08 lb	0.17 lb	0.08 lb	0.08 lb
Dimension	12 x 16-in.	Dia. 11 in.	Dia. 5.5 in.	Dia. 5 in.		Dia. 4.25 in.				
Size				12.5 oz	16 oz	9.5 oz				
Source	2	3	4	5	6	7	8	9	10	11
Cost of one set		$18								
Weight of one set		4 lb								

1. Weight not reported, estimated as half the weight of the large plate
2. "Cafe Trays - 12″ Wx16″D." Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Cafe-Trays—12-inWx-16-inD-c163p21600.html
3. "Polycarbonate Dinnerware Narrow Rim 3 Compartment Plate 11″Diam.x1-1/4″D." Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Polycarbonate-Dinnerware-Narrow-Rim-3-Compartment-Plate-11-inDiamx-1-1-4-inD-c184p3100.html
4. "Polycarbonate Dinnerware Narrow Rim Plate, 5-½″" Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Polycarbonate-Dinnerware-Narrow-Rim-Plate-5-1-2-in-c184p14657.html
5. "Polycarbonate Dinnerware 12-1/2 oz. Nappie Bowl, 5″" Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Polycarbonate-Dinnerware-12-1-2-oz-Nappie-Bowl-5-in-c184p14662.html
6. "Plastic Tumbler - 16 oz." Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Plastic-Tumbler—16-oz-c68p516.html
7. "Polycarbonate Dinnerware 9-9/16 oz. Mug" Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Polycarbonate-Dinnerware-9-9-16-oz-Mug-c184p14664.html
8. "Dominion Flatware - Heavy Dinner Fork" Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Dominion-Flatware—Heavy-Dinner-Fork-c69p11997.html
9. "Dominion Flatware - Heavy Solid Handle Knife" Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Dominion-Flatware—Heavy-Solid-Handle-Knife-c69p12000.html
10. "Dominion Flatware - Heavy Teaspoon" Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Dominion-Flatware—Heavy-Teaspoon-c69p11993.html
11. "Dominion Flatware - Heavy Oval Soup Spoon" Central Restaurant Supplies. Web. 13 June 2013. http://www.centralrestaurant.com/Dominion-Flatware—Heavy-Oval-Soup-Spoon-c69p11994.html

Appendix F: Dishwasher Racks

F.1 Dishrack

A typical dishrack holds (Figure F-1) 20 plates, bowls, or coffee cups. Specifically, two of the three commercial dishwasher examined accommodated 25 dishes/rack and 18 plates/rack (McGuire 2011).

Dishrack dimensions are: 4 x 19.75 x 19.75 in. (HxWxD).

Dishrack cost is $17/rack

Figure F-1. Dishrack.

Source: FSW (2014b).

F.2 Flatware rack

A typical flatware rack (Figure F-2) holds 20 sets of flatware (assuming that one set of flatware is equivalent to one dish).

Flatware rack dimensions are: 4 x 19.75 x 19.75 in. (HxWxD).

Flatware rack cost is: $20/rack

Figure F-2. Flatware rack.

Source: FSW (2014a).

F.3 Cup rack

A typical cup rack (Figure F-3) holds 20 cups.

Cup rack dimensions are: 4 x 19.75 x 19.75 in. (HxWxD).

Cup rack cost is: $17/rack.

Figure F-3. Full-size cup rack.

Source: FSW (2014d).

Appendix G: Shelving Units

A typical shelving unit (Figure G-1) has five shelves, and is supported on swivel casters for mobility.

The cost of a typical shelving unit is $222.

Dimensions of a typical shelving unit are: 69 x 60 x 21 in. (HxWxD).

Figure G-1. Shelf chromate wire mobile cart.

Source: FSW (2014c).

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14. ABSTRACT
DFACs in a contingency environment consume large amounts of energy and resources, and generate large amounts of food and solid waste daily. Almost all Contingency Basecamp (CB) DFACs provide individual paper and plastic ware, which is costly in terms of purchase, transportation, and disposal. This work analyzed the effects of replacing paper and plastic ware with reusable materials, and of adding industrial dishwashers to reduce the logistical burden of using paper and plastic ware. Additional enhancements analyzed were: (1) greywater heat recovery units, (2) solar water heaters, and (3) anaerobic biodigesters. Implementing dishwashing facilities on contingency DFACs was found to be economically viable. Greywater heat recovery was recommended as a standard addition to dish-washing facilities at contingency DFACs. Solar water heating was recommended only at enduring contingency base camps. Anaerobic biodigesters were recommended for base-wide use.

15. SUBJECT TERMS
energy efficient, architectural design, dining facility, sustainable facility

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